UTILITY ADVANCED TURBINE SYSTEMS PROGRAM (ATS)

TECHNICAL READINESS TESTING AND

PRE-COMMERCIAL DEMONSTRATION

CONTRACT NO. DE-FC21-95MC32267

FINAL

QUARTERLY TECHNICAL PROGRESS REPORT TPR-17
for the Period April 1, 2000 to June 30, 2000

to the

U.S. DEPARTMENT OF ENERGY

Office of Fossil Energy

National Energy Technology Laboratory

Morgantown, West Virginia

July 26, 2000

Submitted by

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DISCLAIMER

ABSTRACT

The objective of the ATS program is to develop ultra-high efficiency, environmentally superior and cost competitive gas turbine systems for base load application in utility, independent power producer and industrial markets. Specific performance targets have been set using natural gas as the primary fuel:

- System efficiency that will exceed 60%(lower heating value basis) on natural gas for large scale utility turbine systems; for industrial applications, systems that will result in a 15% improvement in heat rate compared to currently available gas turbine systems.
- An environmentally superior system that will not require the use of post combustion emissions controls under full load operating conditions.
- Busbar energy costs that are 10% less than current state-of-the-art turbine systems, while meeting the same environmental requirements.
- Fuel-flexible designs that will operate on natural gas but are capable of being adapted to operate on coal-derived or biomass fuels.
- Reliability-Availability-Maintainability (RAM) that is equivalent to the current turbine systems.
- Water consumption minimized to levels consistent with cost and efficiency goals.
- Commercial systems that will enter the market in the year 2000.

In Phase I of the ATS program, Siemens Westinghouse found that efficiency significantly increases when the traditional combined-cycle power plant is reconfigured with closed-loop steam cooling of the hot gas path. Phase II activities involved the development of a 318MW natural gas fired turbine conceptual design with the flexibility to burn coal-derived and biomass fuels. Phases I and II of the ATS program have been completed. Phase III, the current phase, completes the research and development activities and develops hardware specifications from the Phase II conceptual design.

This report summarizes Phase III extension activities for a three month period. Additional details may be found in monthly technical progress reports covering the period stated on the cover of this report. Background information regarding the work to be completed in Phase III may be found in the revised proposal submitted in response to A Request for Extension of DE-FC21-95MC32267, dated May 29, 1998 and the Continuing Applications of DE-FC21-95MC32267, dated March 31, 1999 and November 19, 1999.

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EXECUTIVE SUMMARY

The objective of the ATS program is to develop ultra-high efficiency, environmentally superior and cost competitive gas turbine systems for base load application in utility, independent power producer and industrial markets. In Phase I of the ATS program, Siemens Westinghouse found that efficiency significantly increases when the traditional combined-cycle power plants is reconfigured with closed-loop steam cooling of the hot gas path. Phase II activities involved the development of a 318MW natural gas fired turbine conceptual design with the flexibility to burn coal-derived and biomass fuels. Phases I and II of the ATS program have been completed. Phase III, the current phase, completes the research and development activities and develops hardware specifications from the Phase II conceptual design. This report summarizes Phase III activities for the three month period April 1, 2000 to June 30, 2000.

Phase 3 extension originally involved no load testing of the ATS turbine generator. A redefinition of Phase 3 extension tasks was submitted as a continuing application to the Department of Energy on March 31, 1999. The continuing application continues to focus on critical engineering, manufacturing, development and testing to verify the readiness of ATS technology for commercial application. Approval of the continuing application was received in June 1999. A second continuation application was submitted in November 1999.

The new test rig for vane testing was completed and delivered to AEDC. The site installation continues with installation of the various piping systems to support running of the rig.

A full-scale combustor test was performed with the new adaptive noise control algorithm. The test was done on the pilot fuel stage and on one of the pre-mixed stages. The adaptive algorithm was able to determine the appropriate phases for control in both tests. The data is being analyzed now with further tests scheduled in July.

Advanced seal development is in the final data analysis stage prior to initiating rope seal design for the W701DA and W501G engines.

Test samples continue to accumulate high temperature and pressure exposure in the ORNL steam test rig. The next scheduled examination of these samples is planned for August 2000.

The changes at the Waltz Mill test rig in order to improve the control procedure have proven successful. A coated test specimen failed under ATS temperature conditions. The derived time to failure was consistent with prior tests, which validates the stability of the test rig and assures accuracy and reproducibility of results.

The row 1 vane alternative design is progressing well. PCC is finalizing tooling for the necessary wax dies. Final designs for the inner and outer shrouds are complete and it is anticipated that initial castings will be complete in late July.

The steam-cooled component engine test began again on May 5th at the W501G in Lakeland after the first three diaphragms of the compressor were replaced with modified designs.

Additional testing has been done through June including engine thermal testing for component temperatures, cooling airflow and temperature modulation and transition steam flow modulation at full power. The engine was shutdown on June 22nd for a scheduled inspection. Additional testing will continue through the summer months.

Testing continued at the Empire Stateline plant in Joplin, Mo. The engine reached base load and the compressor mass surpassed expectations by 2.7%. Additional testing and validation of monitored parameters proved successful and the unit was turned over to the customer.

Continued evaluation and test of the ATCC3 catalytic combustor module at PCI has shown that the addition of the effusion holes has improved the fuel air distribution along the walls. Further testing is still warranted as there is still not a homogeneous fuel-air mix within the reactor.

INTRODUCTION

BACKGROUND

The National Energy Strategy (NES) calls for a balanced program of greater energy efficiency, use of alternative fuels, and the environmentally responsible development of all U.S. energy resources. Consistent with the NES, an U.S. Department of Energy (DOE) program has been created to develop Advanced Turbine Systems (ATS). The Siemens Westinghouse ATS Program is funded and directed by DOE's National Energy Technology Laboratory (FETC). The technical ATS requirements are based upon two workshops held in Greenville, SC that were sponsored by DOE and hosted by Clemson University. The objective of this 8-year program, managed jointly by DOE's Office of Fossil Energy, and, Office of Conservation and Renewable Energy, is to develop natural-gas-fired base load power plants that will have cycle efficiencies greater than 60%, lower heating value (LHV), be environmentally superior to current technology, and also be cost competitive. The program will include work to transfer advanced technology to the coal- and biomass-fueled systems being developed in other DOE programs.

METHODOLOGY

The Advanced Turbine Systems program is structured into four elements:

- Innovative Cycle Studies
- Utility Advanced Turbine Systems
- Industrial Advanced Turbine Systems
- Technology Base

Within each program element there are several planned phases. For example, the Innovative Cycle Studies element includes two phases.

- Program Definition/Planning Studies
- Concept Development

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- An environmentally superior system that will not require use of post-combustion emissions controls under full-load operating conditions.

- Busbar energy costs that are 10% less than current state-of-the-art turbine systems, while meeting the same environmental requirements.

- Fuel-flexible designs that will operate on natural gas but are also capable of being adapted to operate on coal-derived or biomass fuels.

- Reliability-Availability-Maintainability (RAM) that is equivalent to the current turbine systems.

- Water consumption minimized to levels consistent with cost and efficiency goals.

- Commercial systems that will enter the market in the year 2000.

In Phase I of the ATS program, Siemens Westinghouse found that efficiency significantly increases when the traditional combined-cycle power plants is reconfigured with closed-loop steam cooling of the hot gas path. Phase II activities involved the development of a 318MW natural gas fired turbine conceptual design with the flexibility to burn coal-derived and biomass fuels. Phases I and II of the ATS program have been completed. Phase III, the current phase, completes the research and development activities and develops hardware specifications from the Phase II conceptual design. Phase 3 extension activities focus on critical engineering, manufacturing development, and testing to verify the readiness of ATS technology for commercial applications.

This report summarizes Phase III extension activities for a three month period. Additional details may be found in monthly technical progress reports covering the period stated on the cover of this report. Background information regarding the work to be completed in Phase III may be found in the revised proposal submitted in response to A Request for Extension of DE-FC21-95MC32267, dated May 29, 1998 and the Continuing Applications of DE-FC21-95MC32267, dated March 31, 1999 and November 19, 1999.

RESULTS AND DISCUSSION

11.0 PROGRAM MANAGEMENT

No scheduled activities this report. A quarterly review has been scheduled for early August in Orlando, Florida.

12.0 DEVELOPMENT ENGINEERING

12.1 VERIFICATION TESTS

Vane Cascade Tests AEDC completed all piping systems design and fabrication except inlet piping system. The new test rig was delivered to AEDC on 6/26/00. It was installed on its pad and connected to the exhaust ducting. The low and high-pressure water piping installation is complete except for high-pressure water valves. High and low pressure steam piping installation has been started. Fuel oil piping is complete except for connection to the test cylinder itself.

Turbine Test Data Analysis The 1/3 scale ATS turbine test for the row 1 vane has been completed at OSU and the data reduction of the test results finished. Complete aerodynamic and heat transfer results were obtained using the commercial computational fluid dynamics code TASCflow. These results will serve as a measure of the uncertainty that can be expected from similar analysis of other Siemens Westinghouse gas turbines.

Turbine Root Blade Verification Test The spin testing was resumed in April. Initial results indicate gaps in the data due to temporary open circuit conditions. Better connectors are being investigated. The STC testing was subsequently halted after a failure on the flexible shaft that occurred after 395 cycles. Damage investigation is continuing along with root cause analysis. Based on the testing history and the failure, the testing data is inconclusive and a new test is being planned.

Turbulator Model Tests No scheduled progress to report.

12.2 C. T. ENGINE DEVELOPMENT ENGINEERING

Combustion System Development A full-scale combustor test was performed with the new adaptive noise control algorithm. The dry, low-NOx combustor was used with the active noise control actuator on the pilot fuel stage, then on one of the pre-mixed fuel stages. In both cases, the adaptive algorithm was able to determine the appropriate phase for control. The data will be further analyzed and preparations for additional testing with alternative combustor and actuator configurations. These tests are scheduled for July and will additionally test the robustness of the active noise control system.

Advanced Seal Development Received preliminary results from Techniweave on pressure/cyclic tests on rope seal squeezed between two plates. Cycling affected the rope springback capability. After 30 cycles the springback was reduced by 30%. Received report from Technetics on PM2000 brush seal manufacture. Techniweave issued final testing report which has been reviewed and comments requesting additional confirmation testing were returned. After these final tests sufficient information will be available to start rope seal design for the W701DA and W501G engines.

Thin Wall Casting Development A test matrix was initiated and finalized for the transient liquid phase (TLP) bonding effort to evaluate the range of anticipated bond line orientations across the range of operation temperatures. PCC will begin manufacture of CMSX-4 inner shrouds immediately for pre-bond machining operations and bonding trials.

12.3 MATERIALS DEVELOPMENTAL ENGINEERING

Steam Effects on Materials Test samples continued to accumulate high temperature, high-pressure exposure in the ORNL steam test rig with the next scheduled examination planned for August 2000. A detailed coating plan was submitted by Walbar Metals for applying aluminide coating to the internal passages of the ATS transition. A detail design was performed on the gas generator for transition internal coating furnace. Acceptance of the design is expected the first week of July. A full scale coating trial is planned for the end of July.

Advanced Vane Alloy All seven experimental heats of modified IN-939 alloys have been cast and heat-treated. Currently in queue for mechanical testing.

TBC Life Prediction An EB-PVD coated test specimen failed under ATS temperature conditions at the high heat flux testing facility at Waltz Mill. This derived failure time validates the time to failure obtained in the first successful test in January 2000. The test validates the stability of the test rig assuring reproducibility of test results. SEM observations of the specimen surface have clearly shown that sintering of the ceramic coating contributes to the failure of EB-PVD coatings. Additional metallographic and non-destructive evaluation is ongoing.

ATS NDE Reviewed the latest version of Jentek's Meandering Winding Magnetometer (MWM) as a possible upgrade to the existing system. This new system represents a significant improvement over the first system, which has performed well. Jentek has a unique system that has solved some of our most difficult eddy current challenges and the changes made in the latest version has the potential to measure and rank the remaining life of critical components.

TMF testing row 1 blade alloy Completed low-cycle fatigue testing of IN 939 Specimens at 800, 850 and 900°C with hold times of 0, 15 and 300 seconds. Testing commenced with a hold time of 1800 seconds and is now near completion with results expected in July. Testing to evaluate the effects of coatings on IN-939 creep fatigue properties will commence once the baseline testing has been completed.

Ring Segment Abradable Coating Development University of Cincinnati erosion tests were completed. Additional abradability testing will be carried out at Sulzer. Back plate temperature will be measured to establish the amount of heat generation during rubbing. Sermatech is testing 12 bond coat/backing plate material combinations to address the corrosion issue, which results in abradable coating spallation.

Alternate Alloy Development Phase 1 testing of PWA 1483 in standard heat treatment condition, the LCF tests at 1750° F (A-ratio = 1) as well as HCF tests at 1000° F (A-ratio = 0.2) have been finished. Further HCF and LCF tests on un-coated specimen are in progress. Testing of PWA 1483 in standard heat treatment condition have been finished. HCF/LCF tests on aluminide coated specimens are in progress.

Liquid Metal Cooling Casting No scheduled activity this quarter.

12.4 C. T. MANUFACTURING ENGINEERING

Row 1 Blade and Vane Alternative Design A purchase requisition was released to PCC to begin manufacture of the airfoil cores for all three vanes, (hot cascade, the W501GS equiaxed production vane and the W501G SX production vane), The tooling for this effort has been proceeding on schedule for the test pieces . Final inner and outer shroud casting designs were completed and the CAD models sent to PCC. Camcraft is working on core tooling. The trailing edge core will be completed in mid July and initial castings done in late July.

12.5 GENERATOR DEVELOPMENTAL ENGINEERING

ATS Class G Stator Development. No scheduled activity.

12.6 ADAPTATION TO COAL AND BIOMASS FUELS

No scheduled activity.

13.0 C. T. MANUFACTURING DEVELOPMENT AND TOOLING

13.1 DELETED

13.2 MANUFACTURING & TOOLING DEVELOPMENT ENGINEERING

No scheduled activity.

13.3 DELETED

13.4 MANUFACTURING VERIFICATION TESTS

No scheduled activity.

14.0 ATS TECHNOLOGY VERIFICATION PROGRAM

14.1 STEAM COOLED COMPONENT & AERO-THERMAL DESIGN VALIDATION TEST

The first three diaphragms of the compressor were replaced with modified designs to increase the dynamic dampening. Testing began on May 5th. This engine build incorporated modified row 2 compressor diaphragms as well as compressor stages 1-4 which were instrumented with over 200 strain gages. The unit was shut down after 34 hours of testing for an inspection of the compressor section. The engine was restarted on May 27th for continued testing. Tests were conducted through mid-June testing various parameters including engine control to validate the compressor design criteria across the normal load range. Additionally, engine thermal testing was done for component temperatures, cooling airflow and temperature modulation and transition steam flow modulation at full power. The unit was shut down on June 22 for a scheduled inspection of the compressor and combustion sections. The unit will be reassembled in preparation for continued testing and power generation throughout the summer months.

14.2 ADVANCED VISCOUS COMPRESSOR TEST

Testing continued at the Empire Stateline plant in Joplin, Mo. The engine reached base load and the compressor mass surpassed expectations by 2.7%. Diaphragm strain gage readings were within allowable levels during start and steady state operation. Blade vibration monitors indicated acceptable levels during operations for the compressor and turbine rows monitored. The engine was tuned at full and part load and achieved emissions and stability requirements. The test was considered a success and the unit was turned over to the customer. Data reduction is ongoing and a final review is scheduled for the end of July.

14.3 CATALYTIC COMBUSTOR TEST

The ATCC3 catalytic combustor module was reassembled at H&B Tool and shipped to PCI for additional atmospheric pressure testing. The addition of the effusion holes improved the fuel air distribution along the walls. However, there is not a complete homogeneous mix within the reactor.

The catalytic centerbody pre-mixed pilot was re-tested with the 45-degree swirler fuel injection pilot swirler at PCI after fixing the instrumentation leak. A high fuel air ratio was required to stabilize the lean pre-mixed swirler flame. A CFD analysis is in progress with the hope of improving the stability of the swirler flame by changing the fuel injection hole pattern. Both 55 and 65-degree swirlers have been tested at GASL. The best results to date have been achieved with the 65-degree swirler.

14.4 STEAM COOLED VANE TEST

No scheduled activity.